ADAPTING A BARLEY GROWTH MODEL TO PREDICT GRAIN PROTEIN CONCENTRATION FOR DIFFERENT WATER AND NITROGEN AVAILABILITIES

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Summary. Grain protein concentration is an important determinant of malting barley quality. An existing barley growth model was adapted to estimate grain protein concentration under different growing conditions. Estimated concentrations were close to those observed in experiments conducted in South-eastern Queensland. Simulation analysis showed that the protein concentration increased sharply with increase in applied nitrogen (N) fertilizer rate when grain yield did not respond to the applied fertilizer. The simulations also demonstrated the risk of failing to meet the malting criteria when initial soil mineral N was high or when soil available water was insufficient to meet crop demand.

INTRODUCTION

Barley is grown for both malting and stockfeed purposes in South-eastern Queensland. The most important criterion for grain to be classified as malting quality, and hence to achieve a price premium, is that grain protein concentration be in the range of about 9.0 - 12.0% on a dry weight basis. It is commonly accepted that barley should be grown with a low rate of N fertilizer in areas of rather low soil N. Recent experiments however, show that the protein concentration can be lower than the required minimum when no fertilizer is applied in areas of low soil N (1, 4). It is also known that the concentration increases if the crop experiences a water shortage, particularly towards the end of growth (5). It is important, therefore, to determine the optimal N application rate using information on soil N status and probability of water stress development in order to both maximise yield and achieve malting quality in terms of grain protein concentration. An existing barley growth model (7) was adapted to estimate grain protein concentration from known soil and weather inputs. The model was used in simulation studies to quantify factors that determine grain protein concentration.

MODEL DESCRIPTION

An existing barley crop growth model, as developed by Goyne *et al.* (6, 7), was used as a basis for development of a model for predicting barley grain protein concentration. The original model consisted of five interacting sub-models: phenology (temperature and photoperiod dependent), soil water balance (exponential decay in soil water content in each layer), leaf area index (logistic functions of thermal time, physiological and light competition senescence of leaves), dry matter accumulation (radiation interception and radiation use efficiency) and grain yield. Grain yield is determined by a harvest index approach; a maximum value of 0.45 was used when nitrogen is limiting, and this value was reduced sequentially to 0.41 with increasing nitrogen availability, as derived from experimental findings. Water stress, as indicated by the ratio of water supply to demand, affects both leaf development and leaf senescence. In order to model the N balance and the effect of N deficiency on crop growth, routines describing soil N, N uptake, N distribution within the plant and remobilisation of N from vegetative organs to the grain were added to the original model. These routines were based in general on the approaches described by Sinclair and Amir (8) for their spring wheat model, although significant modifications were made in some areas. For example, their function relating N uptake to fraction of transpirable soil water (FTSW) was used but a maximum rate of 0.25 g N/m^2/day was adopted instead of 0.4 g N/m^2/day, and also N uptake was reduced if soil N concentration fell below a minimum level. In addition, Sinclair & Amir assumed that N uptake ceased after anthesis, an assumption frequently shown by field data not to hold (2, 3). Hence a function for nitrogen uptake after anthesis, if N was available, was developed and incorporated into the model, relating uptake to FTSW and decreasing the maximum uptake rate as the crop progressed from anthesis to maturity. Other major changes included reducing the minimum N concentrations maintained in vegetative material at anthesis for determination of N available for translocation to grain. These values were reduced to 0.8% and 0.7% for stems and leaves respectively, from values of 1.2% and 1.0% used by Sinclair and Amir (8). If N uptake occured after anthesis, all of this N was partitioned to grain and a lesser portion than originally intended was translocated from the vegetative material. All of these functions affect grain N uptake and translocation and hence grain protein concentration. The parameter values and form of some of Sinclair and Amir's other functions, e.g. relating radiation use efficiency to FTSW and specific leaf nitrogen, were examined closely but eventually left unchanged. Initial grain nitrogen model development concentrated on the barley cultivar Grimmett, although the growth model had been developed also for culivars Tallon, Gilbert and Skiff.

MODEL EVALUATION

Model performance was tested by comparing simulated total N uptake, grain yield and grain protein concentration with experimental results obtained in seven experiments at sites in South-eastern Queensland (Dalby, Warwick, Gatton and Redland Bay (1, 3, 4)), covering a wide range of soil nitrogen and water availabilities and rainfall patterns. Some of these data sets had been used in model development. Daily weather data were obtained from nearby weather stations and input for each simulation. Five of these experiments had both irrigated and rainfed treatments while the other two were only rainfed. Seasonal rainfall varied between 46 and 240 mm. Soil profile depth was 1.4 m in all simulations, except one where a shallower profile was observed, and soil available water ranged between 90 and 280 mm. Two N fertiliser treatments were compared, -N and +N, and in the +N treatment the amount of N applied varied between 80 and 100 kg N/ha among the experiments. Initial soil mineral (NO_3 + NH_4) levels for these simulations were obtained from field data for each experiment with levels ranging between 20 and 120 kg/ha.

Figure 1. An indication of model performance on prediction of yield, N uptake and grain protein concentration for seven experiments in South-eastern Queensland (IRR=irrigated treatments, RFD=rainfed treatments).

There was generally good agreement between observed and simulated results for 24 data pairs with correlation coefficients being 0.91, 0.86 and 0.67 for total N uptake, grain yield and grain protein concentration, respectively (Fig. 1). In a few cases, N uptake was underestimated by more than 20% and this resulted in underestimation of grain yield.

Determination of grain protein concentration. The simulated and observed responses of grain protein concentration and grain yield to N application rate obtained at Gatton in 1989 under rainfed conditions and in 1990 under irrigated conditions are shown in Fig. 2. These two cases are chosen because of their contrasting responses. Initial soil mineral N (NO_3 + NH_4) content was high (152 kg/ha) in the 1989 rainfed site, resulting in no yield response to applied N rate. Grain protein concentration increased sharply in this case, and exceeded 12% at all of the application rates except 0 kg N/ha. In the 1990 irrigated experiment the initial soil N content was low (63 kg/ha) and grain yield responded sharply to applied N to 40 kg/ha. Grain protein concentration was below the 9% level with N application rates of up to 40 kg/ha but it increased with further N application, although remaining below 11% even at a N application rate of 100 kg/ha. Simulated results were similar to those observed, except at the very high N rate where both yield and protein concentration were underestimated.

Figure 2. Observed and simulated responses of grain protein concentration and yield to N application, Gatton 1989 rainfed and 1990 irrigated.

Other simulations were conducted for rainfed crops using 1994 meteorological data from Redland Bay, Brisbane, following an experiment there in which results had indicated that the barley crop responded to irrigation. Initial soil N level was moderate (9.6 and 54.1 kg/ha in 0-15 cm and 15+ cm layers respectively) and this level was altered to 50%, 125% and 150% of the original level for the simulations. The results suggested that at low initial soil N levels, grain protein concentration is likely to be too low for malting purposes even at high N application rates at this site and in this season (Table 1).

Table 1. Simulated grain protein concentration (%) at N fertilizer rates of 0, 33, 67 and 100 kg N/ ha and at four levels of initial mineral soil N, under rainfed conditions at Redland Bay, Brisbane.

N fertilizer rate	Soil N level			
	50%	100%	125%	150%
0	4.9	7.4	8.6	9.9
33	6.6	9.4	9.8	11.7
67	7.2	9.6	11.3	12.8
100	7.3	9.8	11.4	12.9

On the other hand, as indicated by the result with 150% of the initial soil N level, grain protein level can be too high if a moderate amount of fertilizer (67 kg/ha) is given. These simulation results indicate the importance of initial soil mineral N in determining grain protein concentration thus accurate estimation of soil N would assist growers decisions about N fertiliser application.

IMPLICATIONS OF SIMULATION STUDIES

The simulations have showed that the model can adequately predict grain protein concentration under different soil nitrogen and water conditions, as well as highlighting the importance of initial soil mineral N levels and the timing and degree of water stress in determining final grain protein concentration. The response of grain protein concentration to N and water is therefore site and season specific. The effect of N application rate on the probability of attaining grain protein concentration levels within the quality limits, as well as maximising yield, can be calculated using simulation studies with historical rainfall data for individual locations in key production regions.

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